Modeling and Optimization of Pre-conditioned LPP targets

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What modeling is needed for…

Prediction / optimization of…

i) Source geometry
ii) CE
iii) Radiated spectra (EUV, DUV)
iv) Debris (ions, neutral particles, nano-fragments…)

Variable parameters …

Laser pulse parameters

i) wavelength
ii) duration
iii) focus spot
iv) pulse energy (power density)

……..

Target type

i) flat
ii) droplet
ii) modified droplet (prepulse)

…………

MODELING TOOLKIT
RnD ISAN / EUVLabs

RZLINE

RHD (LPP DPP)

2D(r,z) Hydro-Dynamic and Radiative Transfer

Diffusion-like radiation transfer in 100-5000 groups

with high resolution in-band EUV region and DUV

The code RZLINE, provides various physical data which are of interest for applications: CE, anisotropy of the radiation, the spatial dimensions of the source, energy and angular and charge distribution of ions, the amount of non-evaporated substance, etc.

MODELING TOOLKIT
RnD ISAN / EUVLabs

THERMOS
Atomic physics
Kinetics
Opacity & Emissivity

BELINE
ATR
Ray-tracing
Radiation transport
Detailed spectra

Two software packages intended for data preparation, in-line calculations and post processing

1. **THERMOS-BELINE - self-consistent calculation of level kinetics and radiation transport including overlapped spectral lines with arbitrary optical thickness and realistic line profiles, Long characteristics method.**
2. **Verified atomic database for Li, Sn, Gd, Tb and their mixtures.**
3. **Details see elsewhere …. "High Energy Density Physics", V.3, 2007, p. 198-203**

MODELING TOOLKIT

RnD ISAN / EUVLabs

THERMOS
Atomic physics
Kinetics
Opacity & Emissivity

BELINE
ATR
Ray-tracing
Radiation transport
Detailed spectra

STAR-CCM+
Prepulse target modification

RZLINE
RHD LPP DPP

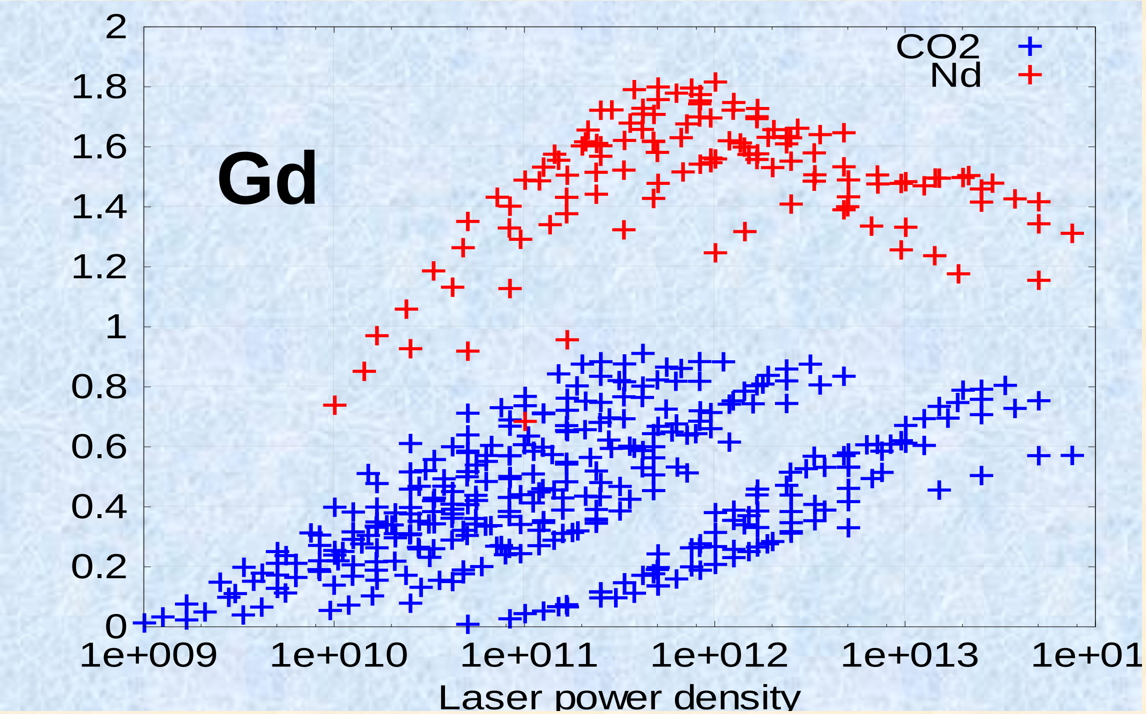
M2DGD
Hydrogen flow with Sn fragments in chamber

PIC code
Fast ions & neutrals distribution

MODELING TOOLKIT

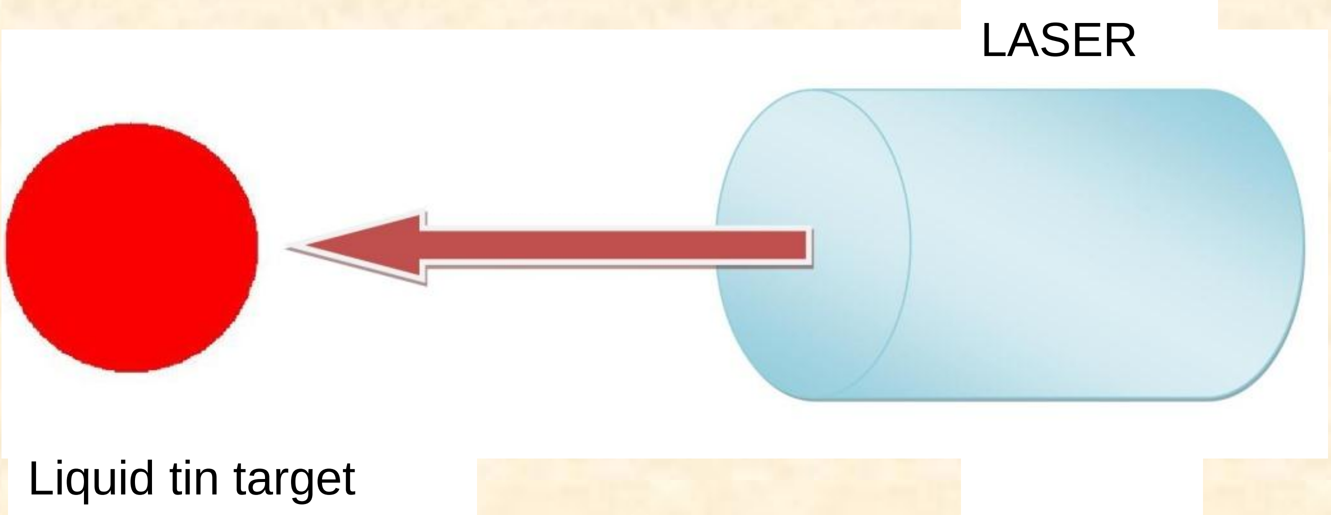
RnD ISAN / EUVLabs

Due to parallel computing
mass calculations are possible



Results of multi-parametric scaling for Gd LPP source

Target modification by pre-pulse

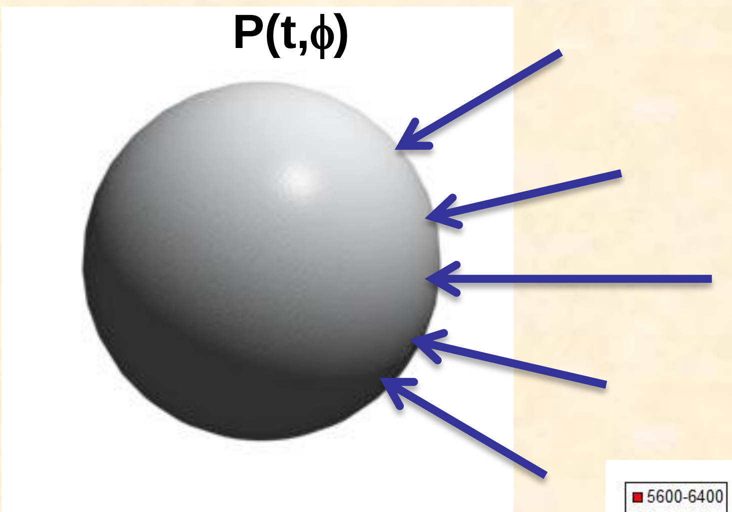


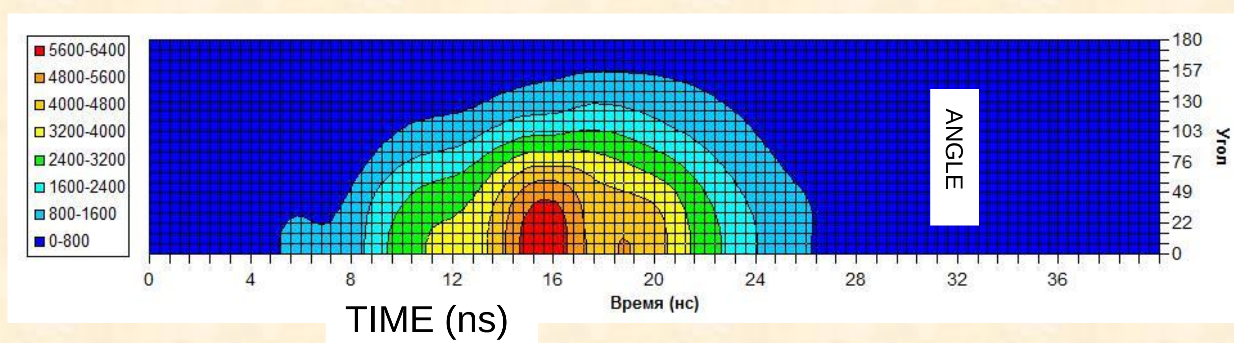
3 steps:

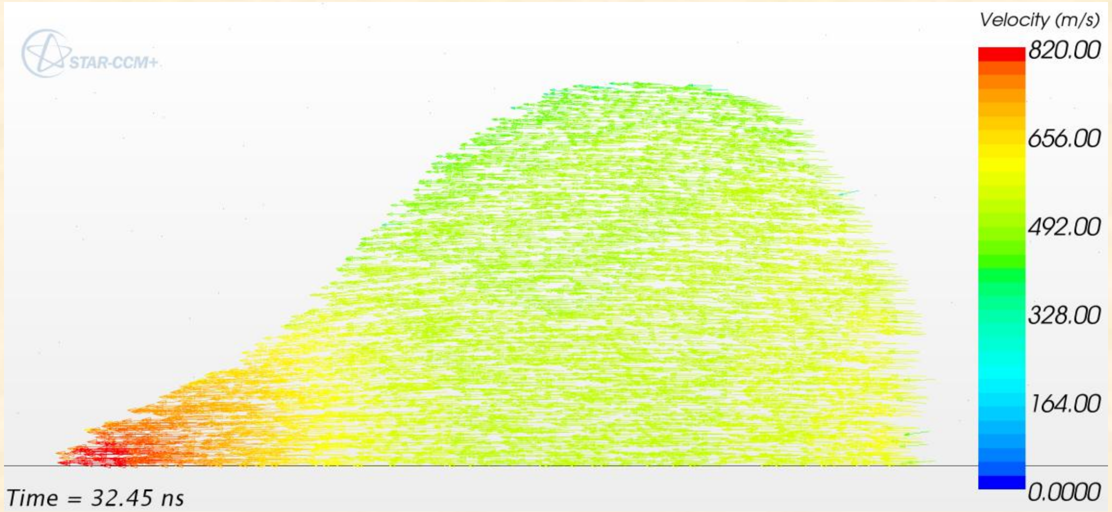
1. Axisymmetric modeling of initial laser impulse impact.
2. Axisymmetric modeling of deformation and movement of tin droplet target.
3. 3D modeling of a target fragmentation.

Target modification by pre-pulse

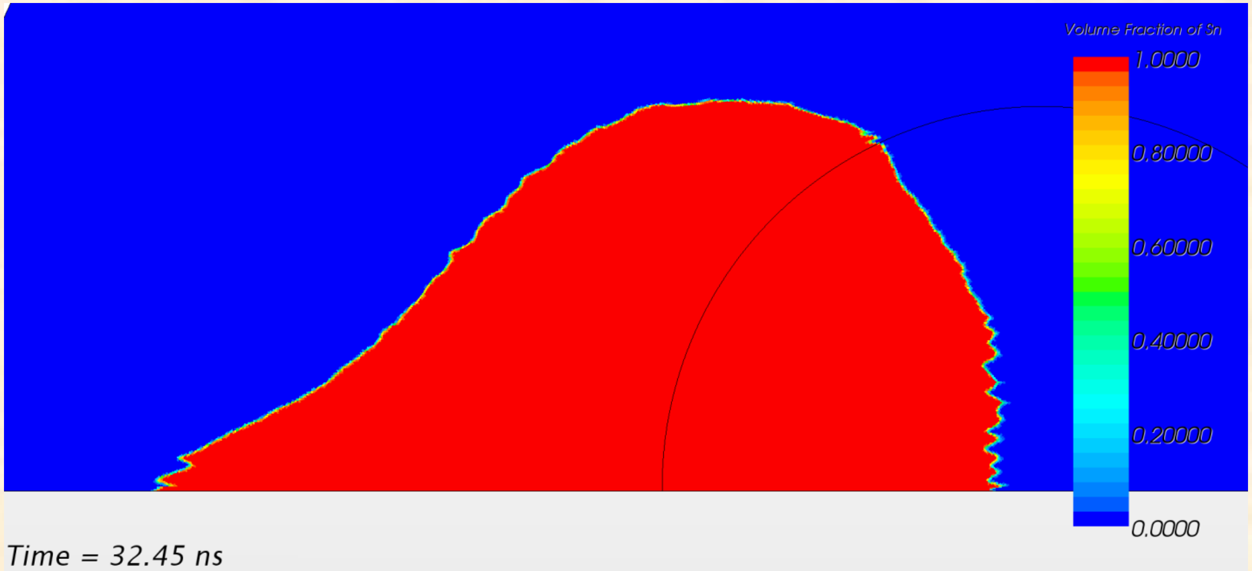
Step 1 – Calculation of initial plasma pressure with the help of RZ-LINE







распределение скоростей в капле



Финальное распределение объёмной доли олова

Step 2 – Calculation of liquid tin droplet evolution with the help of STAR-CCM+

Used Physics Models and Settings

- **Space:** Axisymmetric
- **Time:** Implicit Unsteady

- **Material:** Multiphase Mixture, Eulerian Multiphase

- **Volume of Fluid (2-phases)**
  - **1st phase (molten tin):** Liquid with Constant density
    - Density = 7000 kg/m^3
    - Dynamic Viscosity = 0.16 Pa-s
  - **2nd phase (outside the drop):** Ideal Gas
    - Molecular Weight = 118 kg/kmol
    - Specific Heat = 176.15 J/kg-K

- **Multiphase Interaction, Surface Tension (0.63 N/m)**
- **Multiphase Equation of State**

- **Segregated Flow**
- **Viscous Regime:** Laminar

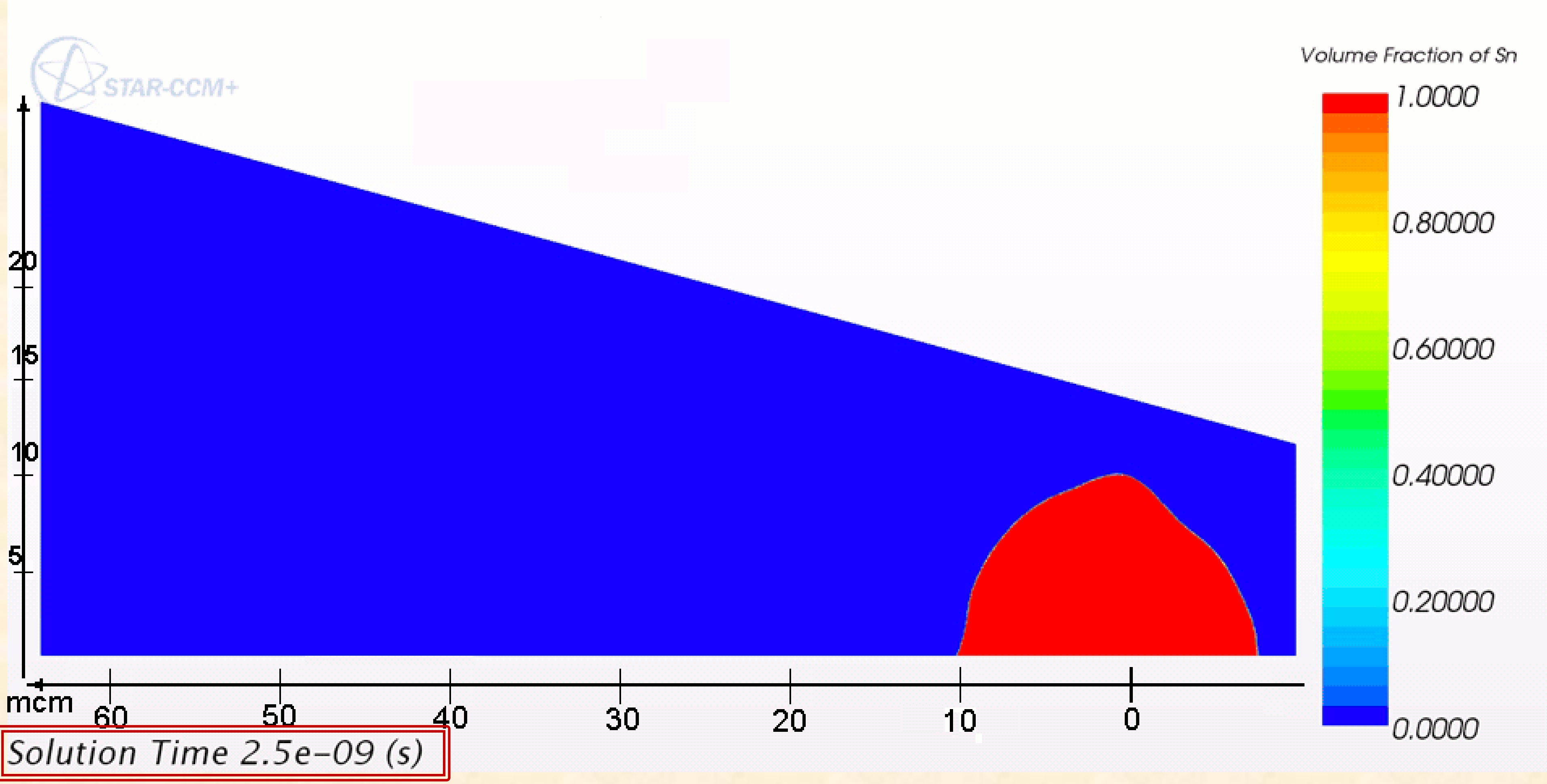
Target modification by pre-pulse

STAR-CCM+ provides the world's most comprehensive engineering physics simulation inside a single integrated package. Much more than just a CFD solver, STAR-CCM+ is an entire engineering process for solving problems involving flow (of fluids or solids), heat transfer and stress. It provides a suite of integrated components that combine to produce a powerful package that can address a wide variety of modeling needs. These components include:

- **3D-CAD modeler**
- **CAD embedding**
- **Surface preparation tools**
- **Automatic meshing technology**
- **Physics modeling**
- **Turbulence modeling**
- **Post-processing**
- **CAE Integration**

STAR-CCM+ is based on object-oriented programming technology. It is specifically designed to handle large models quickly and efficiently using a unique client–server architecture that seamlessly meshes and simultaneously solves and post-processes over multiple computing resources without requiring additional effort from the user. STAR-CCM+ recently became the first commercial CFD package to mesh and solve a problem with over one billion cells.

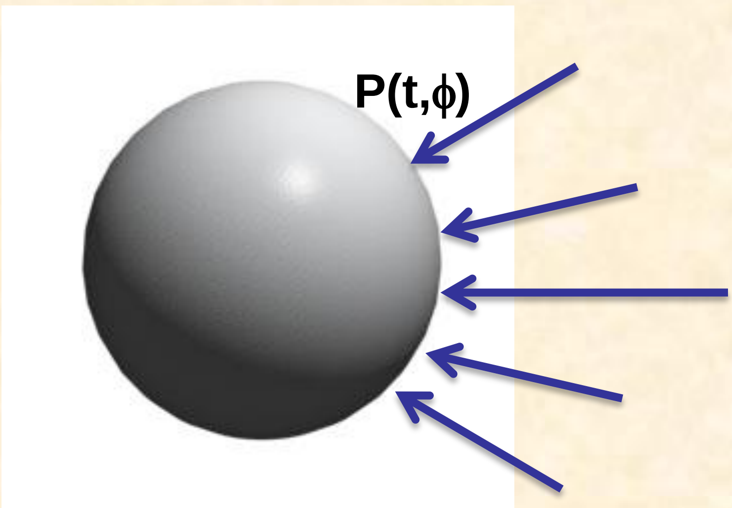
Target modification by pre-pulse



Target modification by pre-pulse

Modification of droplet target during laser pulse.

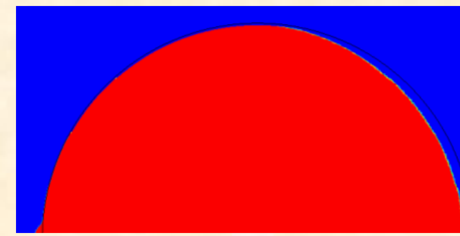
1 stage. Calculation of droplet acceleration under laser pulse load



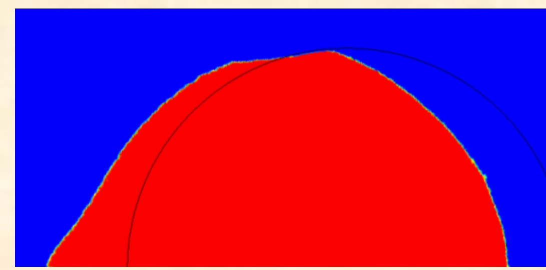
Axi-symmetric pressure distribution is applied at the droplet surface

Droplet shape after laser inpact

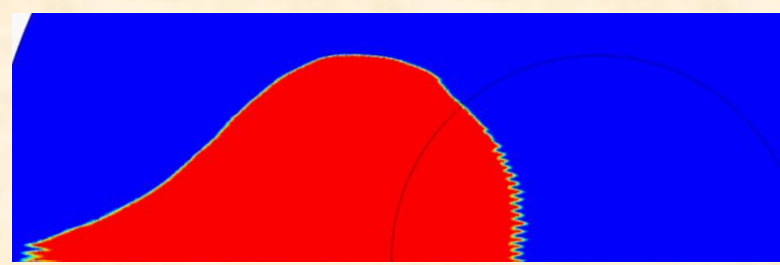
Weak (V_{max}= 100 m/s)



Medium (V_{max}= 300 m/s)



Strong (V_{max}= 800 m/s)

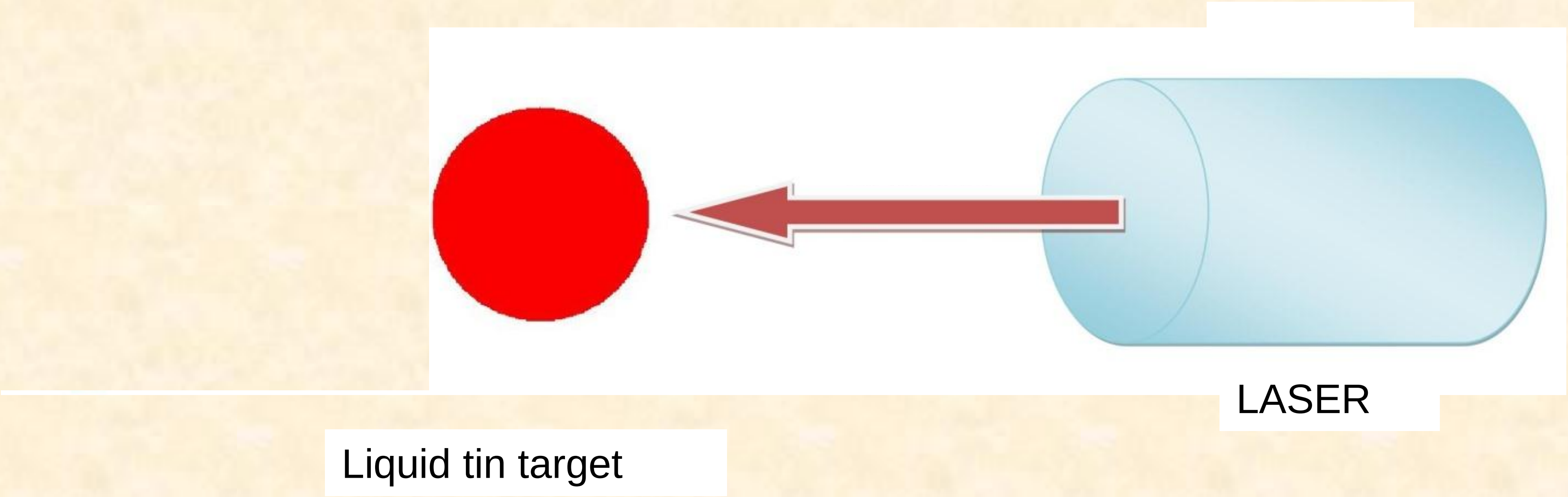


Initial droplet position is shown by black line

Target modification by pre-pulse

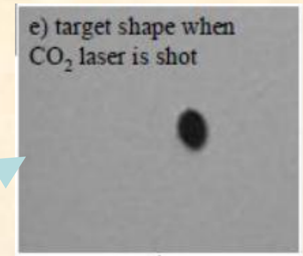
Pre-pulse target modification

Target modification during the “main” laser pulse



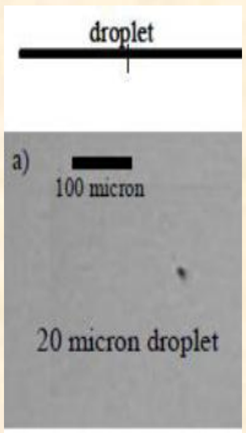
Different types of targets : modeling

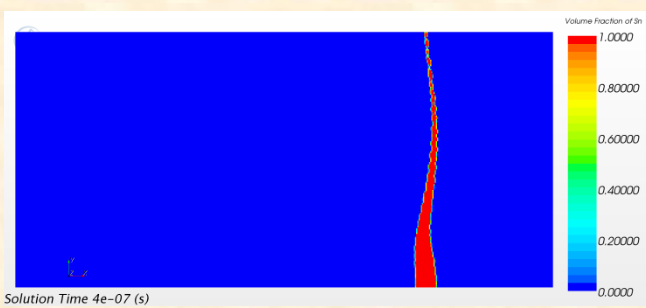
New target shape

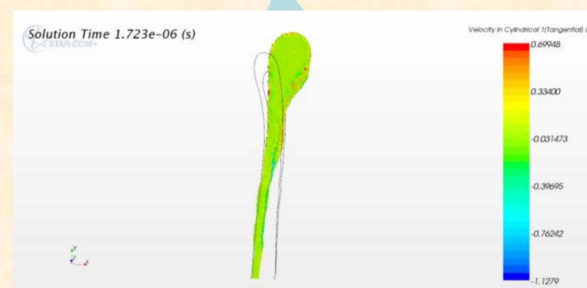


Types of targets:

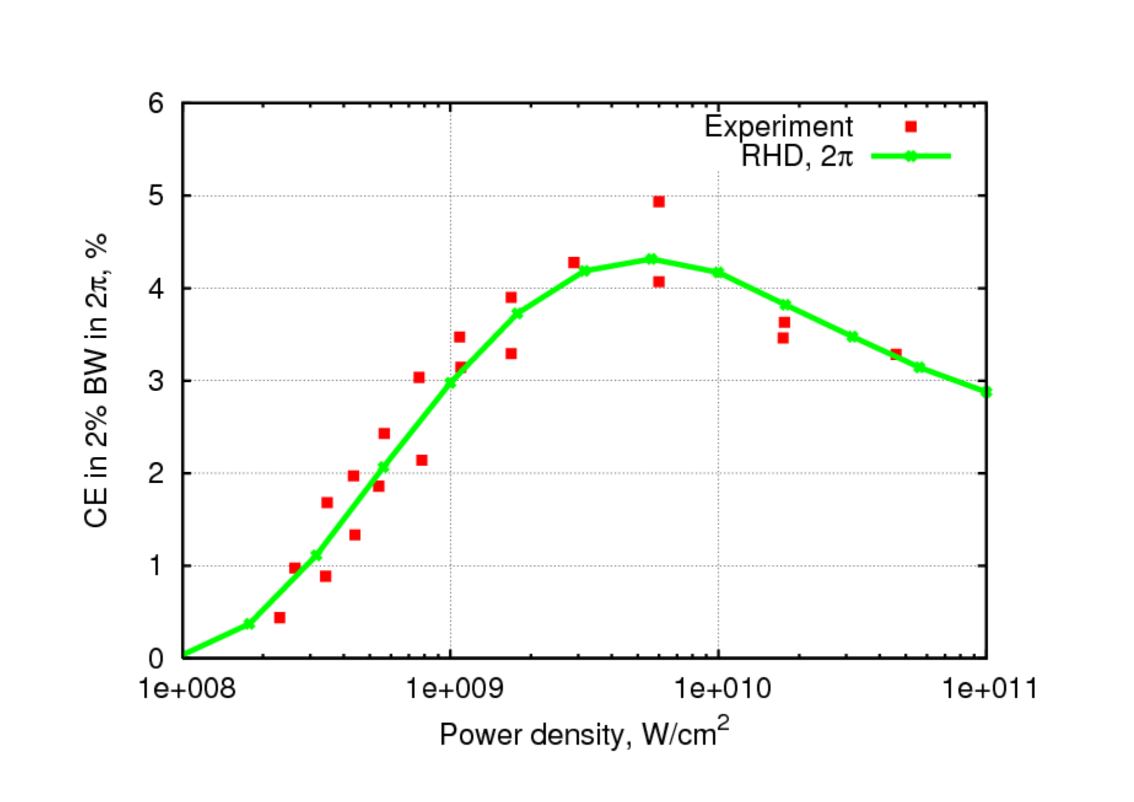
i) flat targets
ii) droplet
iii) modified droplets:
a) liquid tin pancakes
b) mist clouds of nano-fragments.
c) torus clouds
c') pancakes with central hole







Flat target

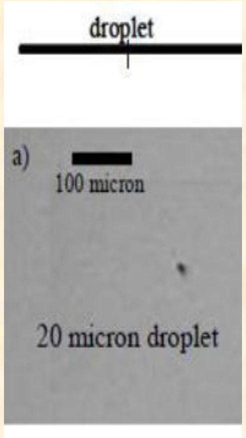


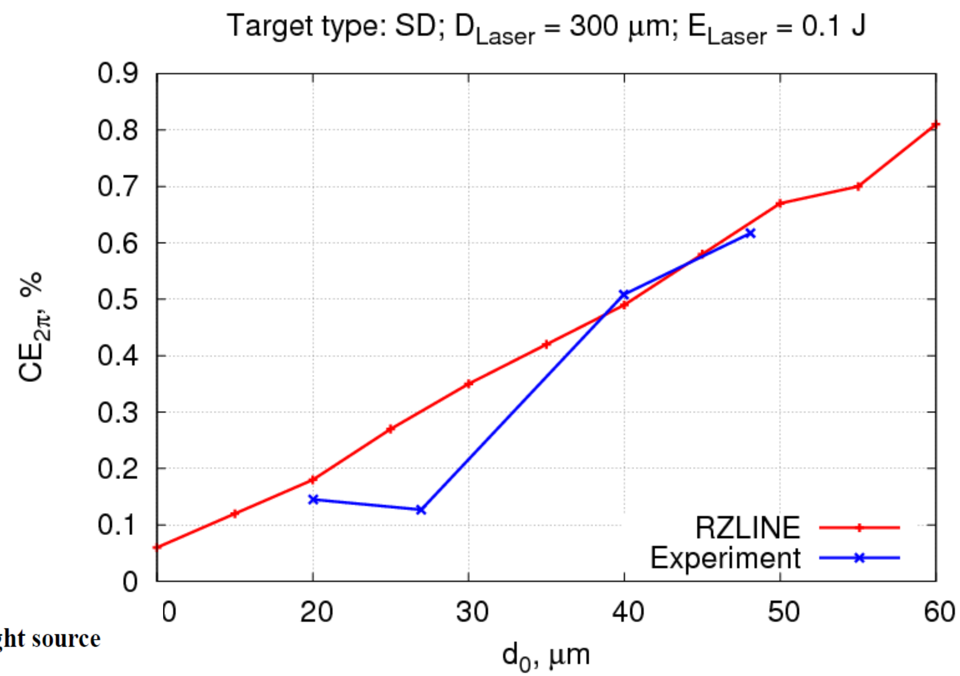
Experiment : Fomenkov Igor V., Ershov Alex I., Partlo William N. et al. Laser produced plasma light source for EUVL. 2011. P. 796933–796933–6.

Tin droplet target

Experiment

Modeling





Development of laser-produced plasma based EUV light source technology for HVM EUV lithography

Junichi Fujimoto, Tsukasa Hori*, Tatsuya Yanagida*, Takeshi Ohta*, Yasufumi Kawasuji*, Yutaka Shiraishi*, Tamotsu Abe*, Takeshi Kodama*, Hiroaki Nakarai*, Taku Yamazaki* and Hakaru Mizoguchi

Gigaphoton Inc. 400 Yokokurashinden Oyama-shi Tochigi-ken 323-8558, JAPAN
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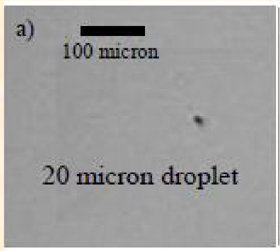
Target modified by pre-pulse

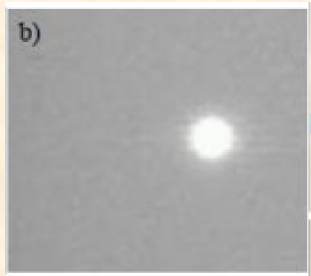
Experiment

Modeling

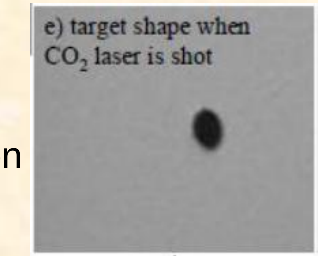
New target shape



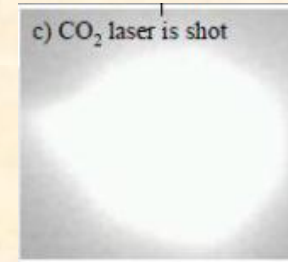
Laser prepulse

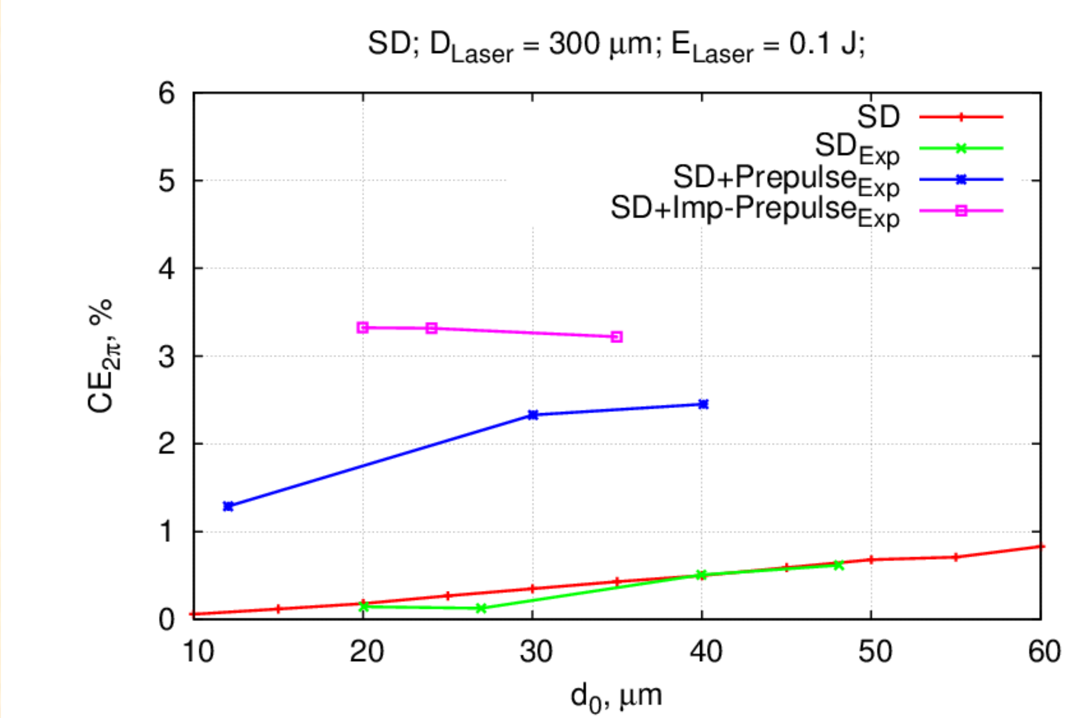


Target modification

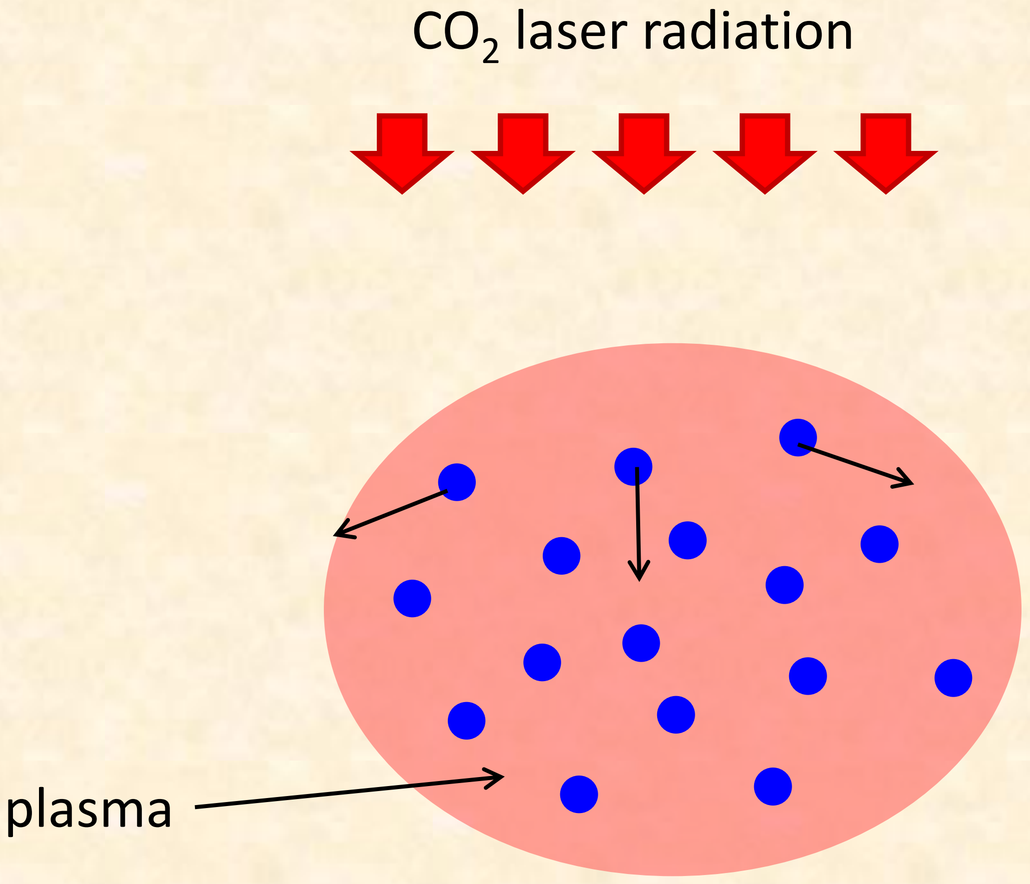


CO2 laser





Distributed(mist) target in RZLINE

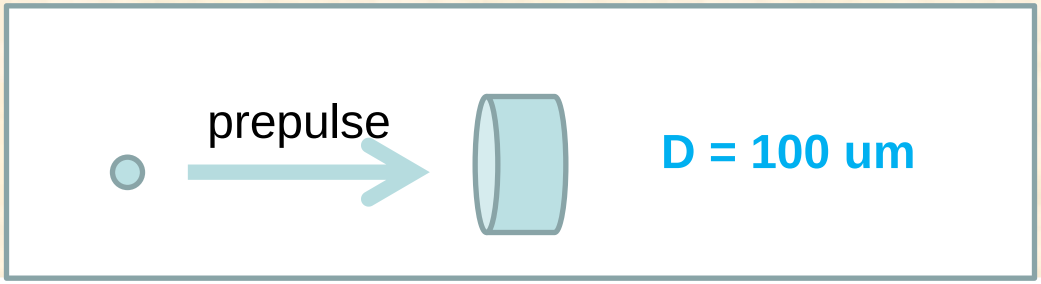


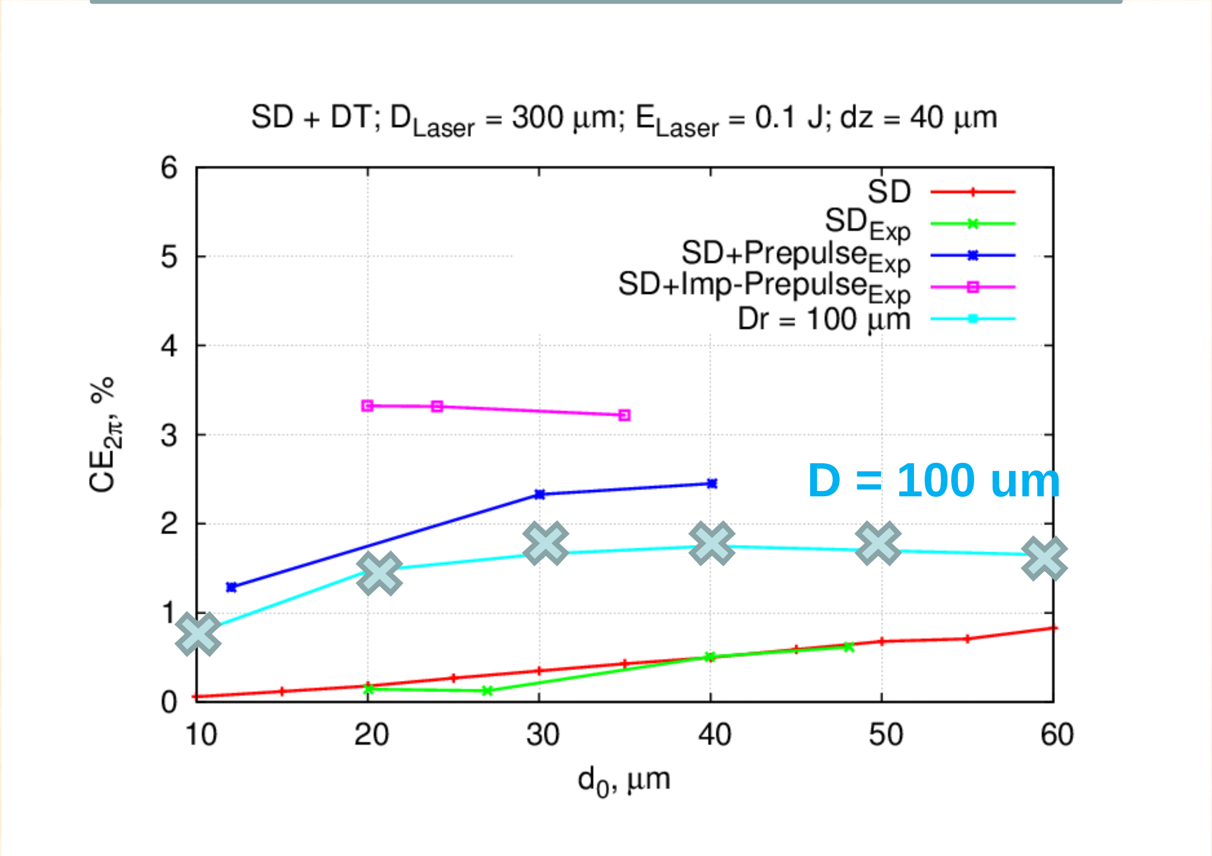
1. Rate of evaporation of fragment (droplet) of some size is a function of plasma parameters around fragments: temperature, velocity, pressure as well as laser intensity near it
2. Fragments are moving during laser pulse under action of plasma

Target modified by pre-pulse

Experiment

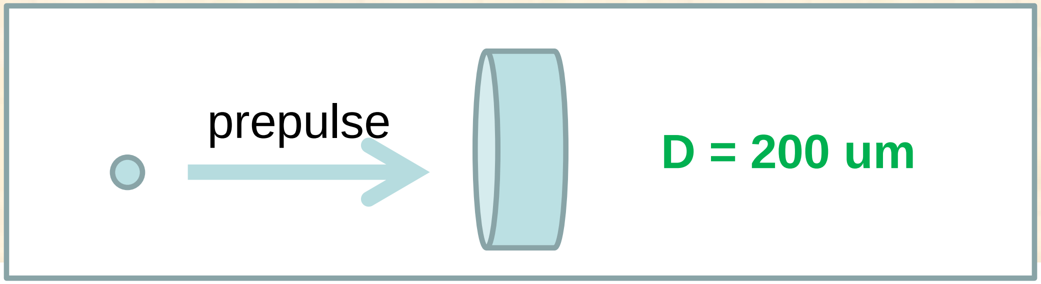
Modeling

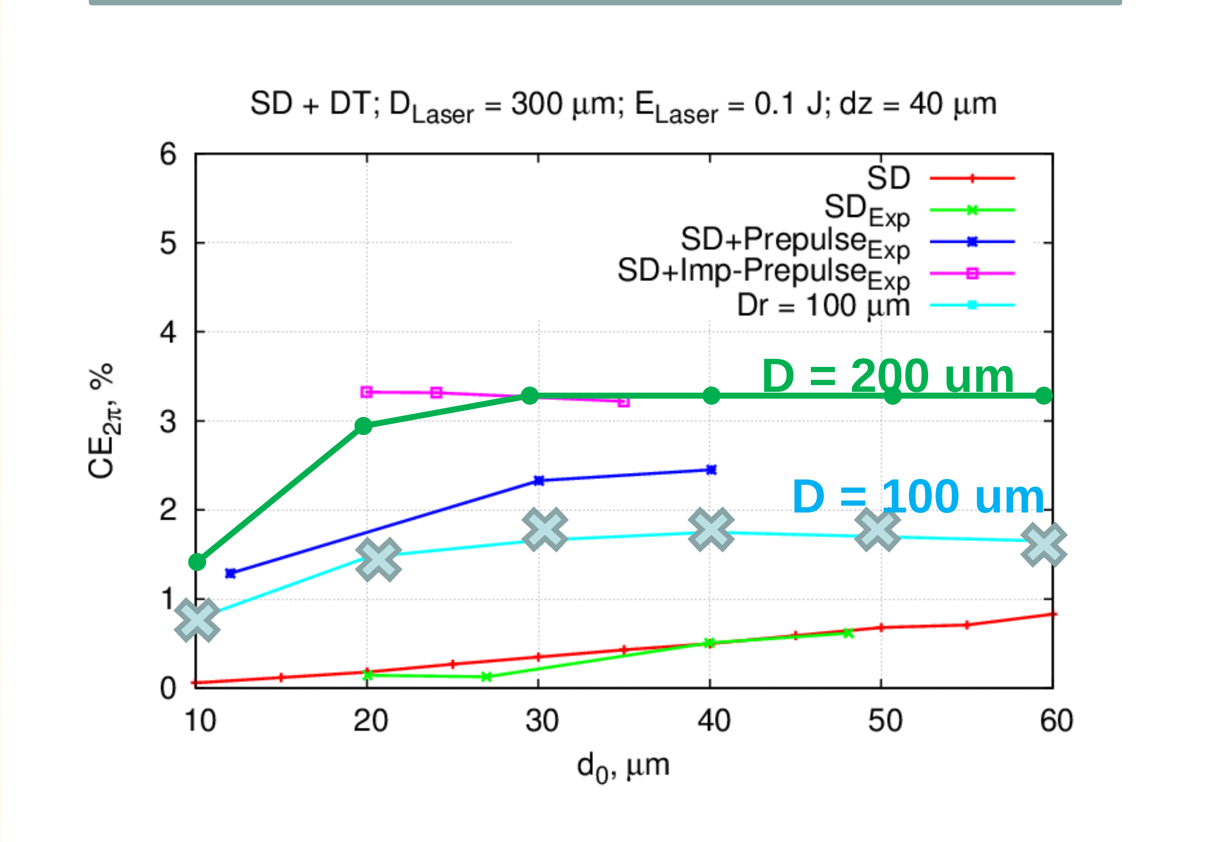




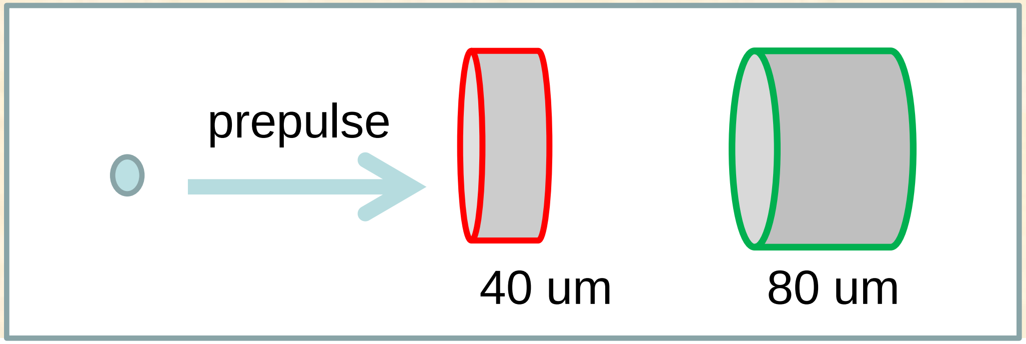
Target modified by pre-pulse

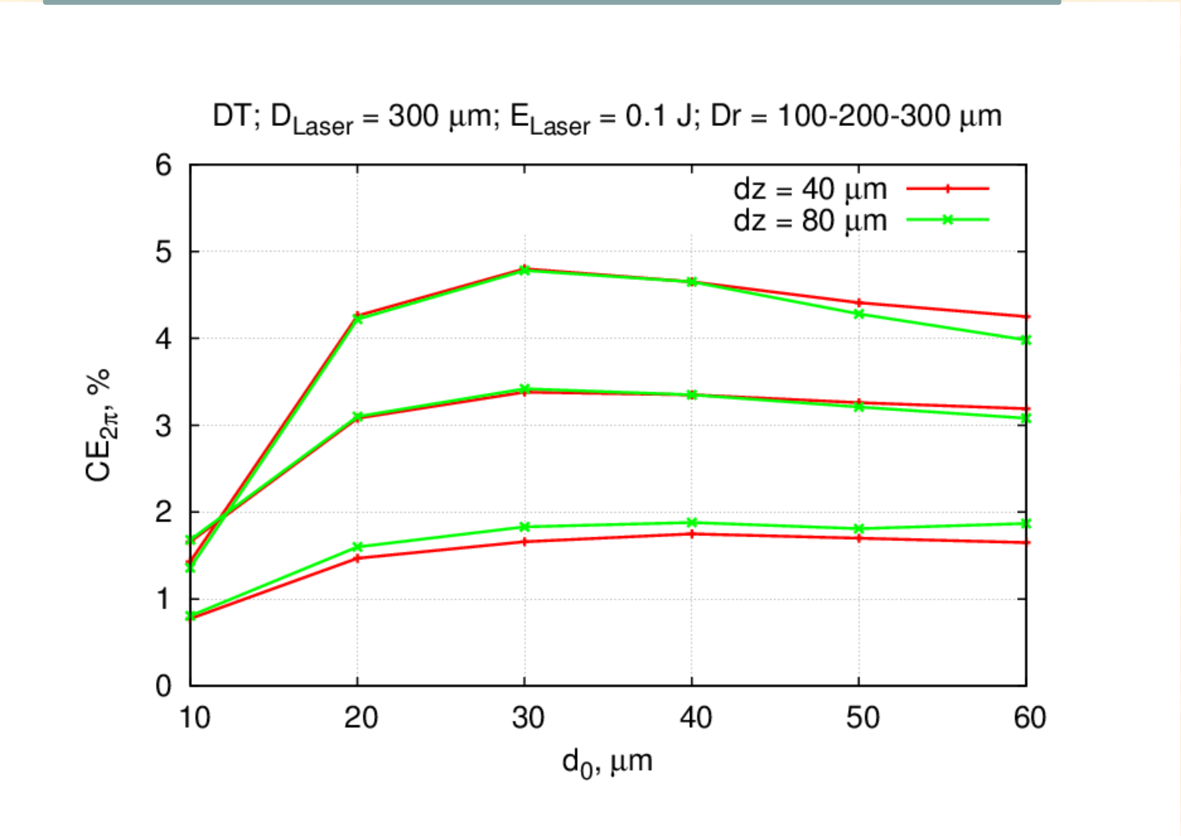
Experiment ⟷ Modeling



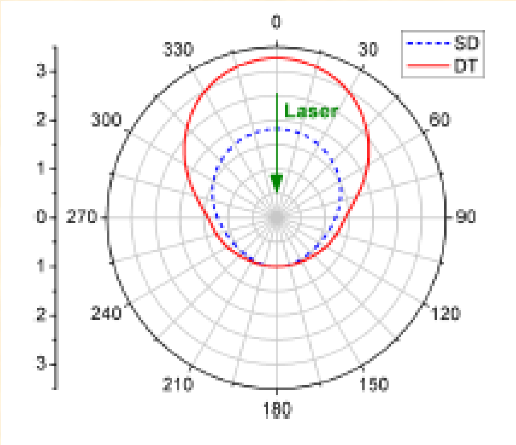


Target modified by pre-pulse

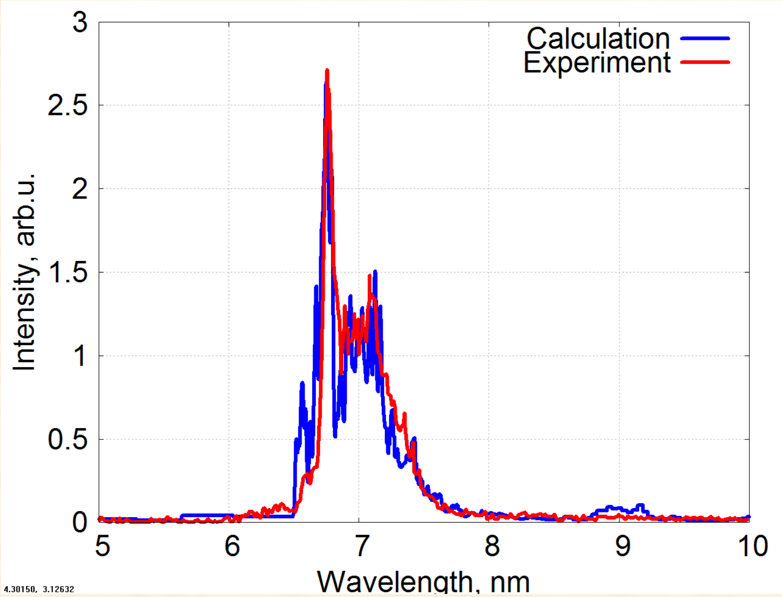


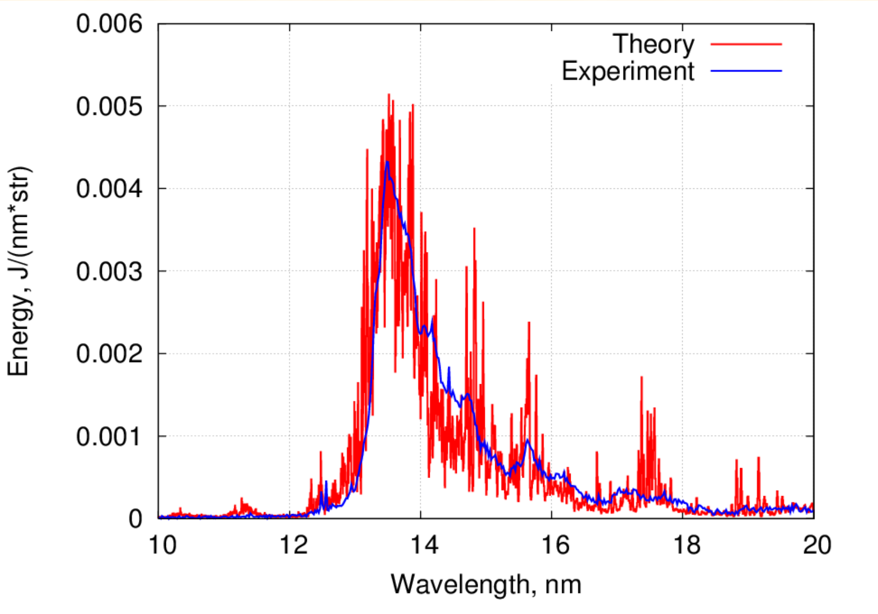


Detailed spectra and anisotropy of radiation are available



Gd spectra ***comparison with experiment*** **Sn spectra**



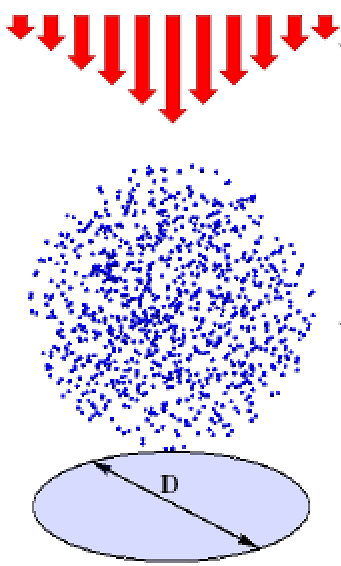


Comparison of characteristics of droplet (SD) and distributed (mist) targets

Poster S54 (this Workshop)

Modeling of Plasma Dynamics and EUV Generation for Distributed Sn Targets Irradiated with Short Laser Pulses

V. Ivanov1, A. Grushin2, V. Novikov2, V. Medvedev3, V. Krivtsun1, A. Yakunin4, and K. Koshelev1

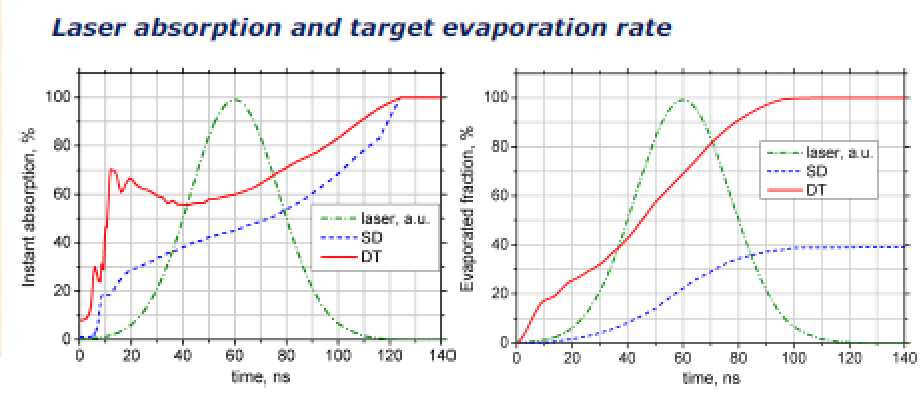


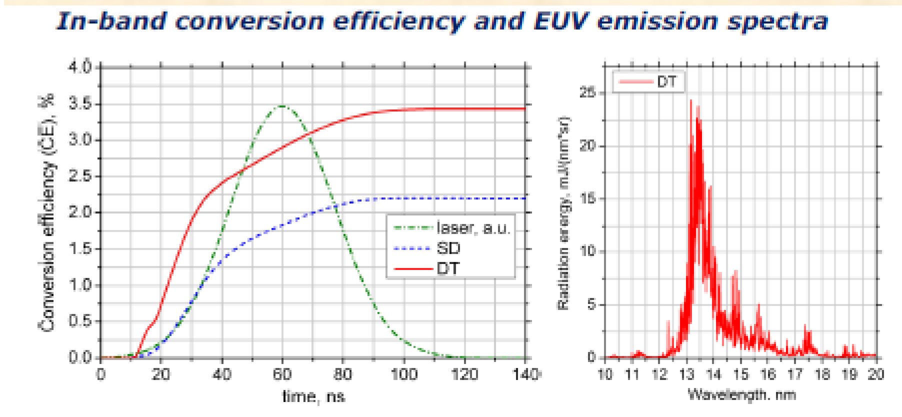
Laser parameters

- 10.6 μm wavelength
- 1.0 J pulse energy
- 40.0 ns FWHM (Gaussian)
- 200 μm beam (Gaussian, $1/e^2$ intensity level)

Target parameters

- D = 300 μm sphere
- d = 1 μm fragments
- total mass = 50 μm droplet mass





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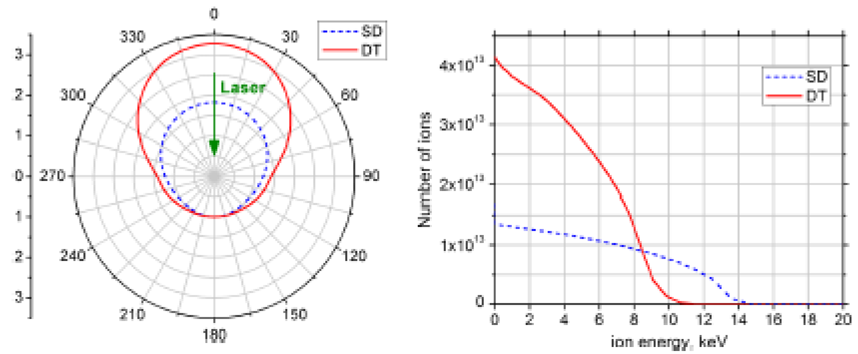
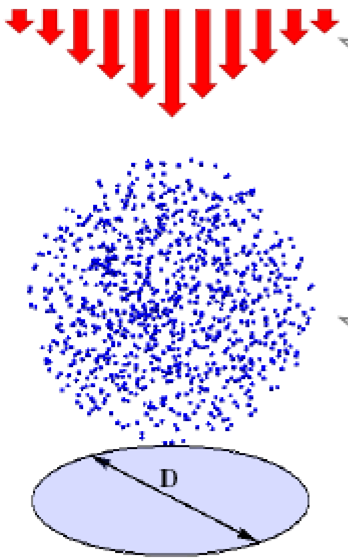
V. Ivanov1, A. Grushin2, V. Novikov2, V. Medvedev3, V. Krivtsun1, A. Yakunin4, and K. Koshelev1

Anisotropy of EUV emission (left) and kinetic energy spectra of Sn ions (right)





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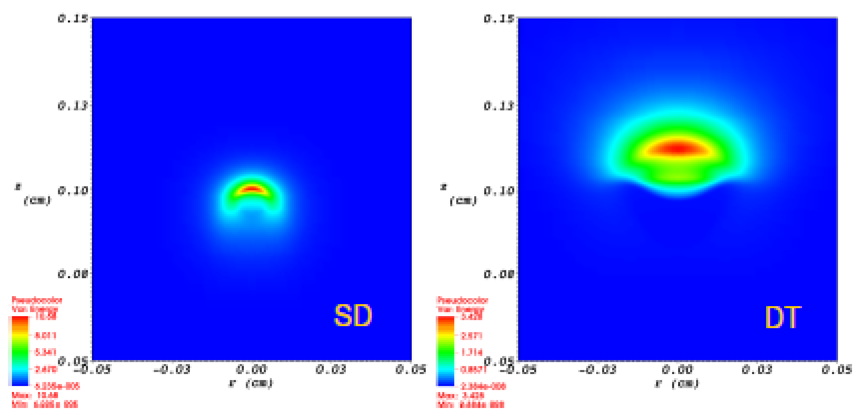
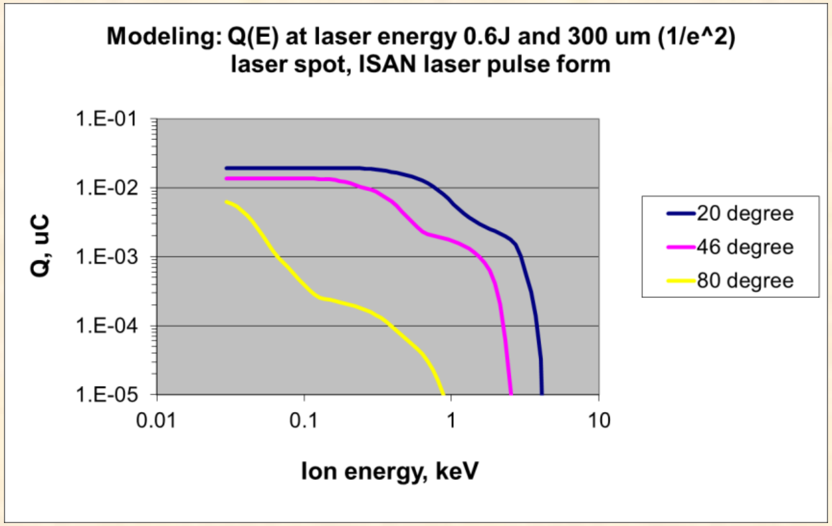
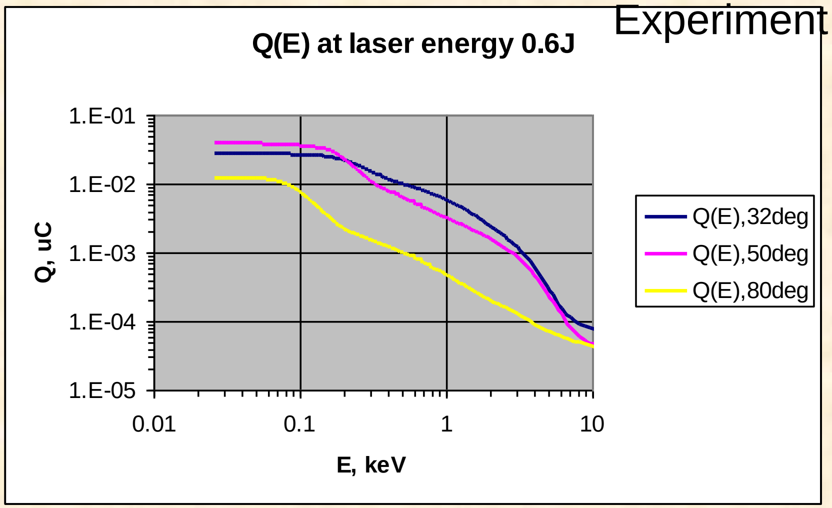
EUV source size



Ion energy spectra
ISAN experiments and modeling results comparison



Experiment



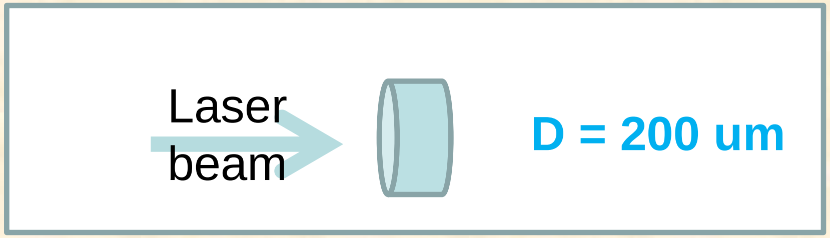
"+"

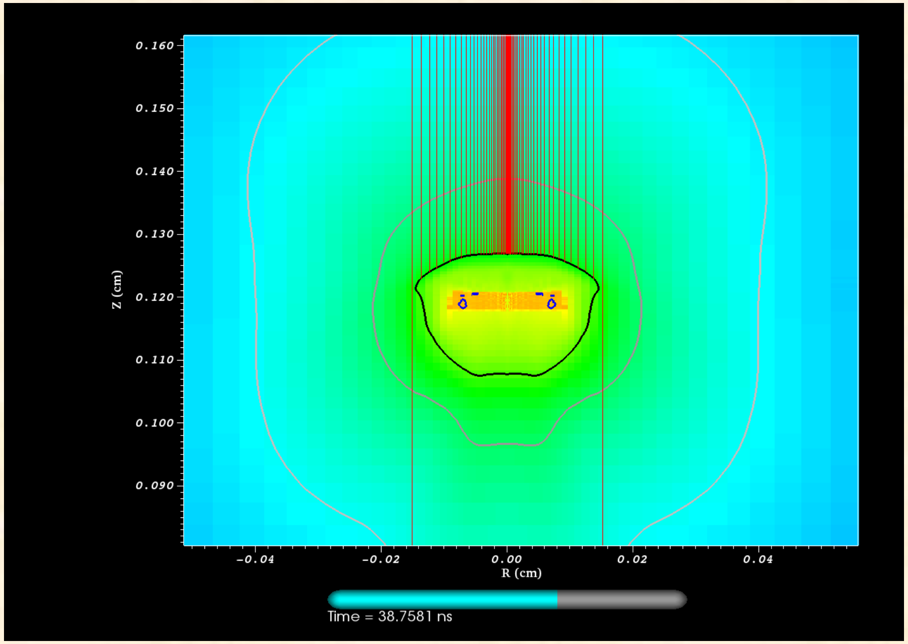
1. **Qualitatively correct energy and angle dependence**
2. **Close values of overall number of total charge**
3. **Realistic values of maximal ion energy**

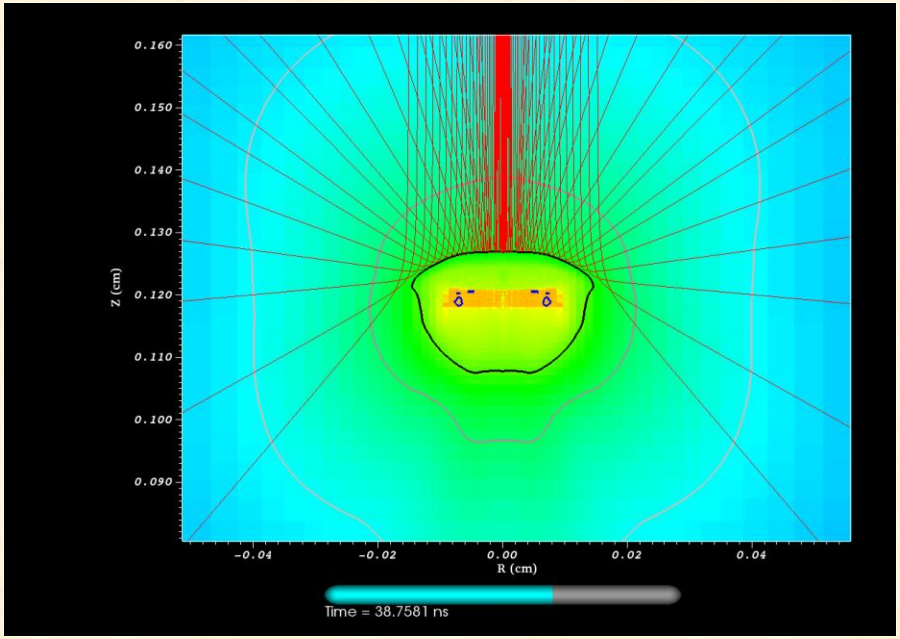
"-"

1. **Absence of Maxwell-like tail in modeling**

Laser beam refraction effects in plasma

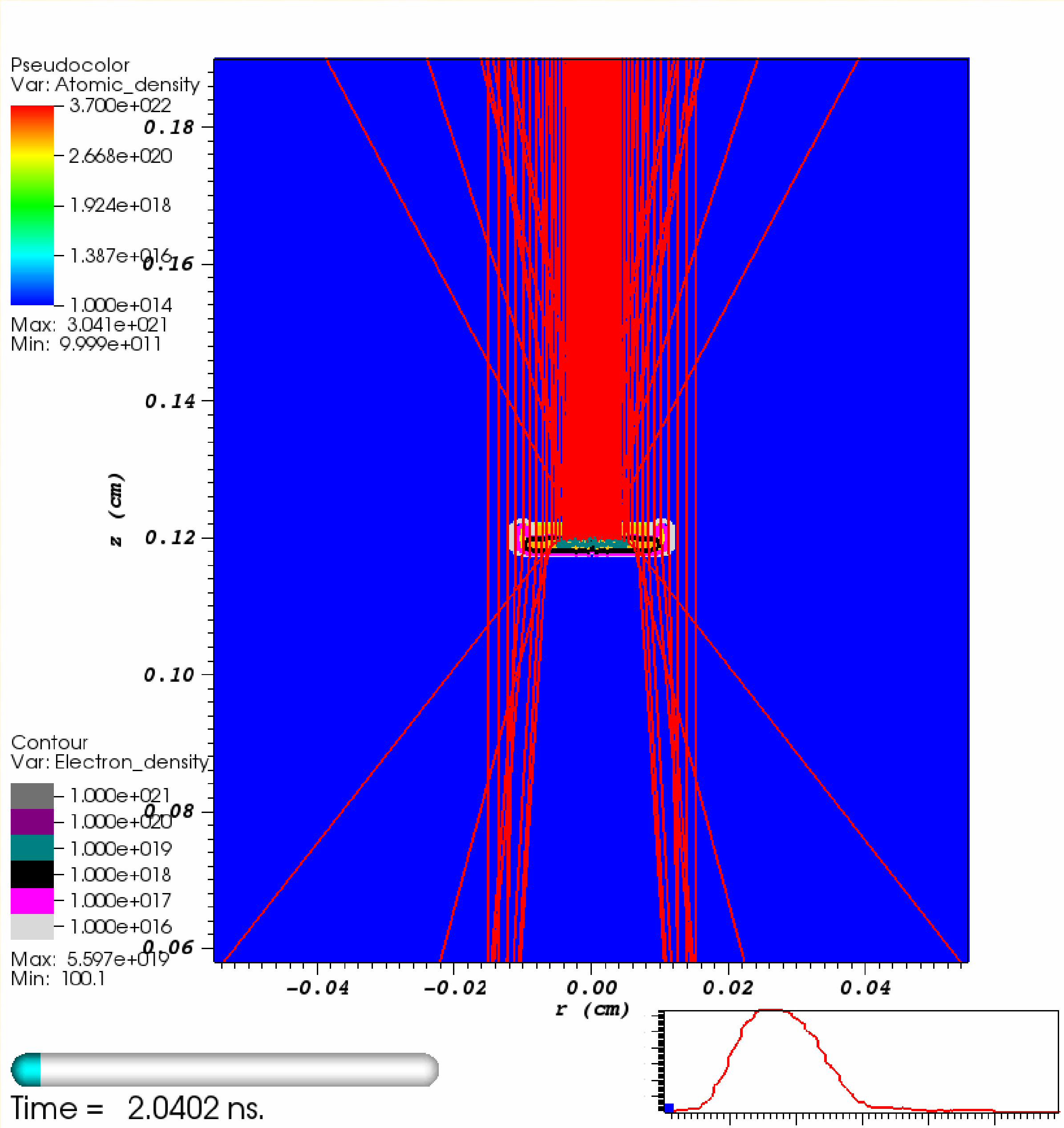




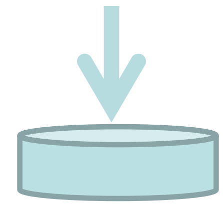


Without refraction effects

With refraction effects



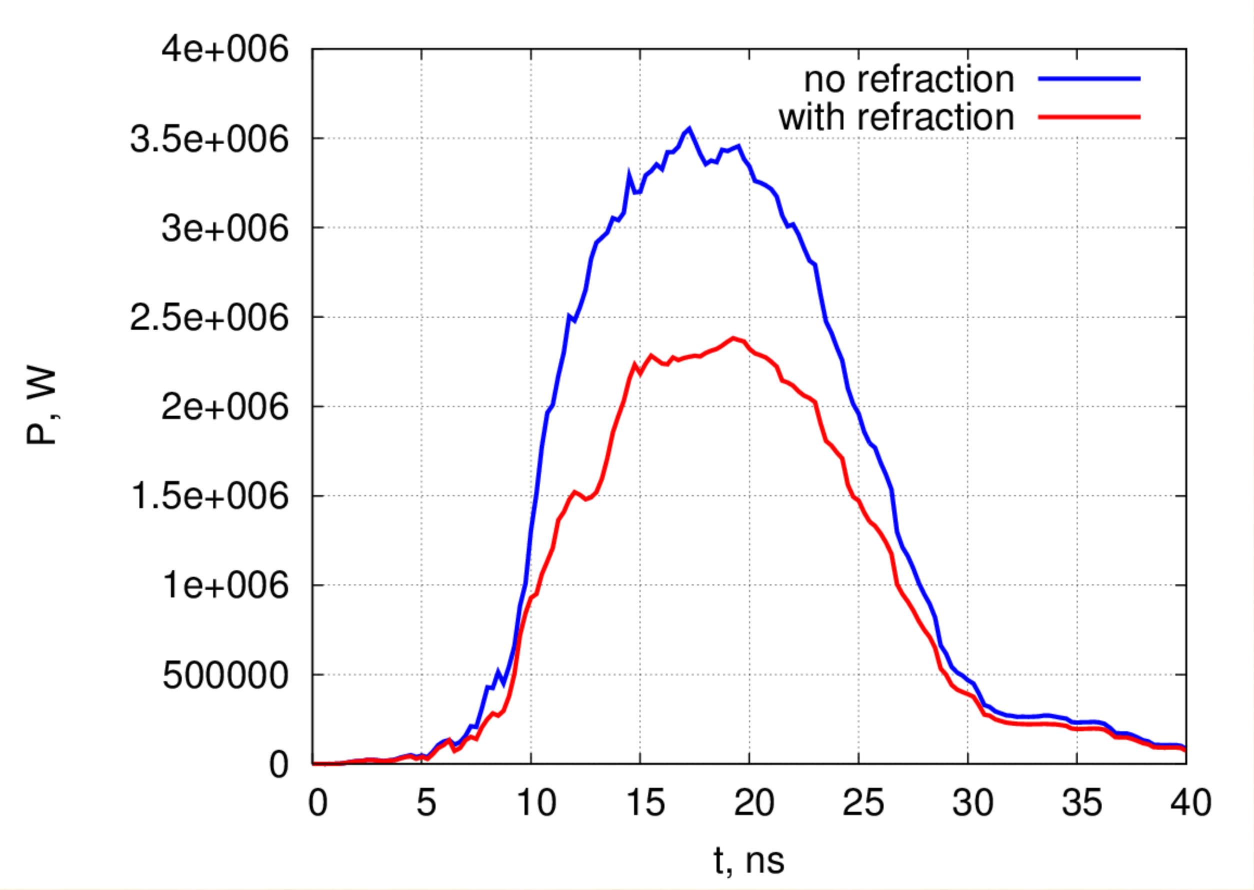
Laser beam 0,1 J; 15 ns



D = 200 um

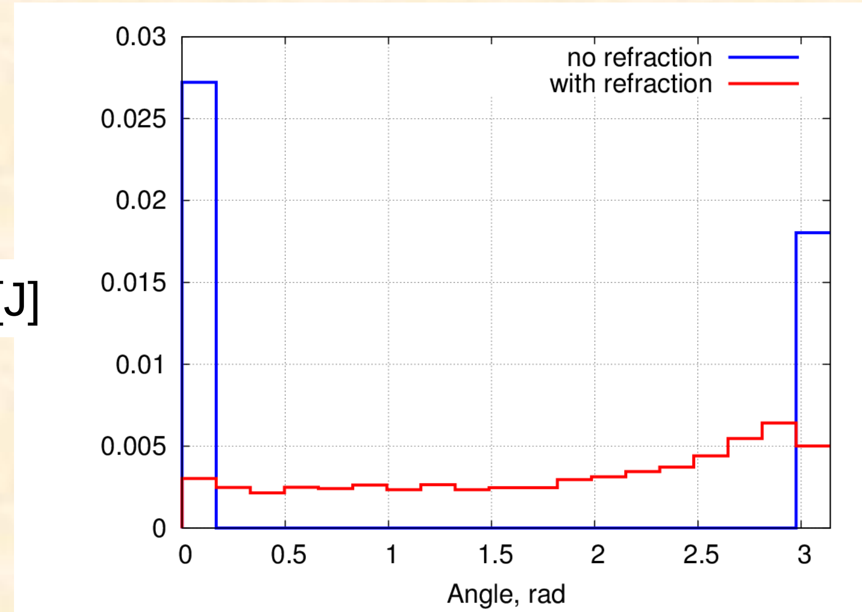
Distributed target; d_F= 1 **um**

Absorption of laser beam in plasma

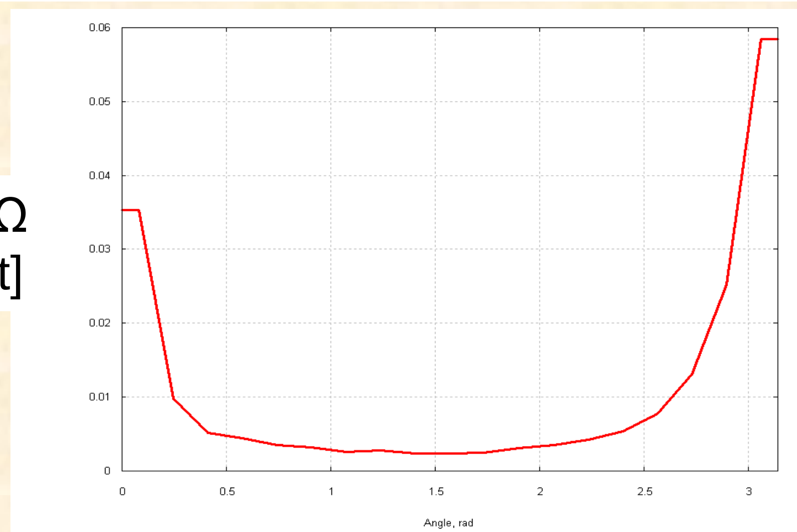


Angular distribution of scattered IR

E[J]



dE/dΩ [J/st]

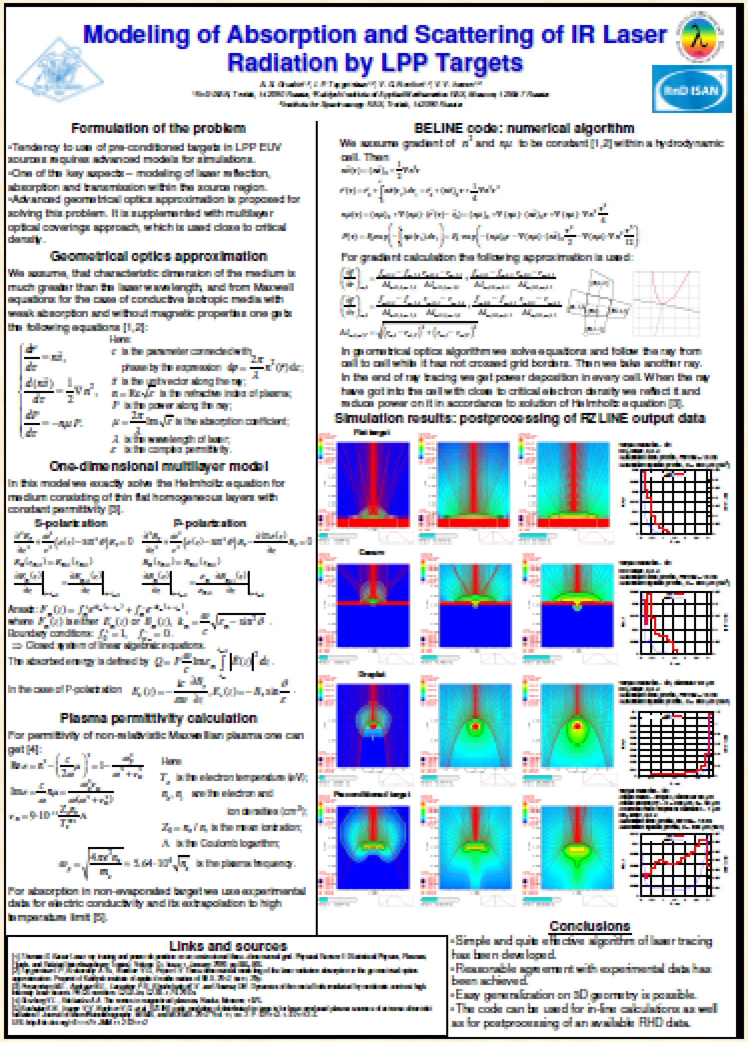


Poster S53 – this Workshop

Modeling of Absorption and Scattering of IR laser Radiation by LPP Targets

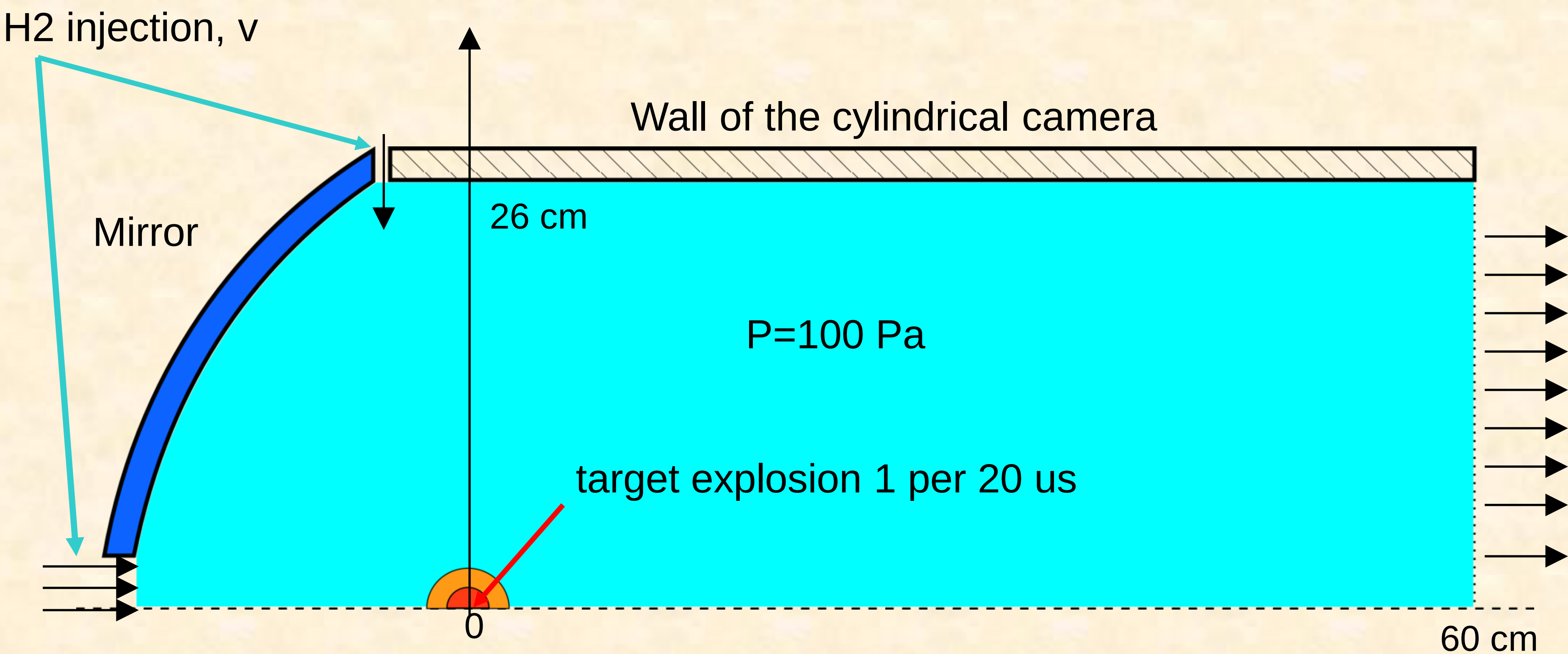
A. S. Grushin1,2, I. P. Tsygvintsev1,2, V. G. Novikov1,2, V. V. Ivanov1,3

1RnD-ISAN, Troitsk, 142090 Russia
2Keldysh Institute of Applied Mathematics RAS, Moscow, 125047 Russia
3Institute for Spectroscopy RAS, Troitsk, 142090 Russia



Modeling of debris production / mitigation

Propagation of Sn in a target chamber with H2 flow



2D axial-symmetric multi-component gas flow

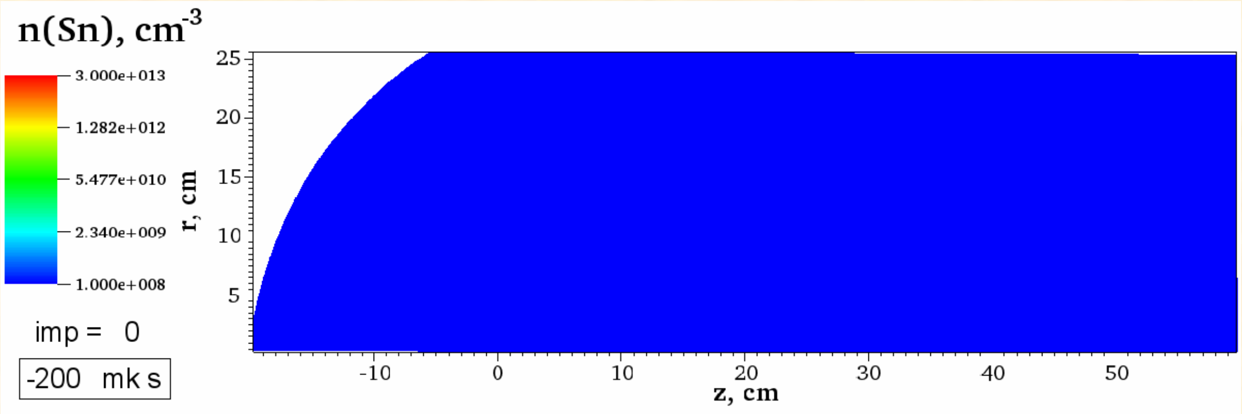
Sn interaction with H_2 flow

by using M2DGD code (Igor Menshov)

- 2D axial-symmetric compressible multicomponent gas flow calculation -

is based on:

- Finite-volume method that uses Godunov's scheme for exact solving of Riemann problem.
- MUSCL parabolic reconstruction with van Albada limiter for derivatives.
- Explicit-implicit scheme for time integration, that gives flexibility in choosing time-step value. In case of explicit use the method gives 2-nd order time approximation as "predictor-corrector" method.
- Solving nonlinear equations system with explicit-implicit scheme is realized using iterations with Newton method and relaxation scheme by pseudo-time. The approximate linearization of the inviscid fluxes is based on the method of Men'shov and Nakamura that can be considered as an extension of the LU-SGS approximate factorization method.
- `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5.477e+010
2.340e+009
1.000e+008
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r, cm
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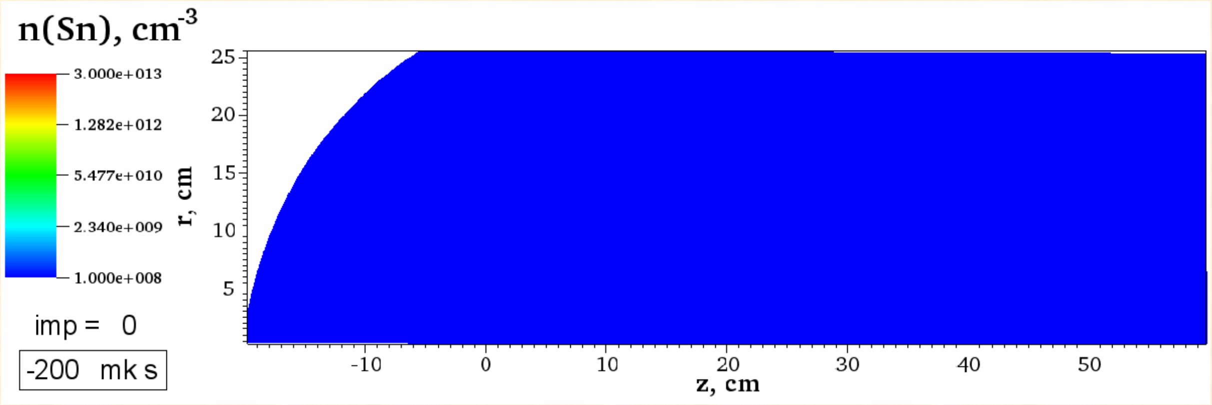
20
15
10
5
-10
0
10
20
30
40
50
z, cm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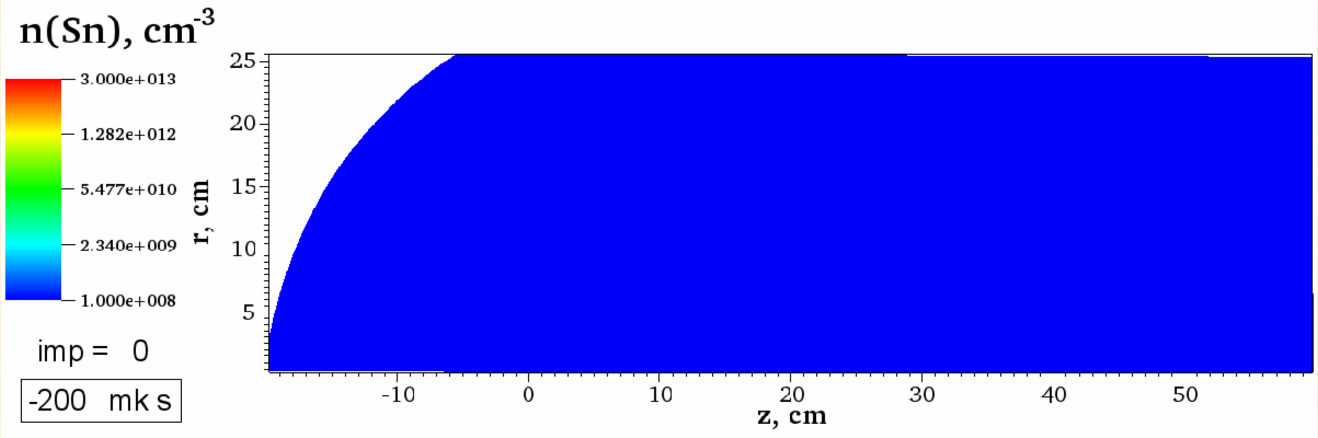
z, cm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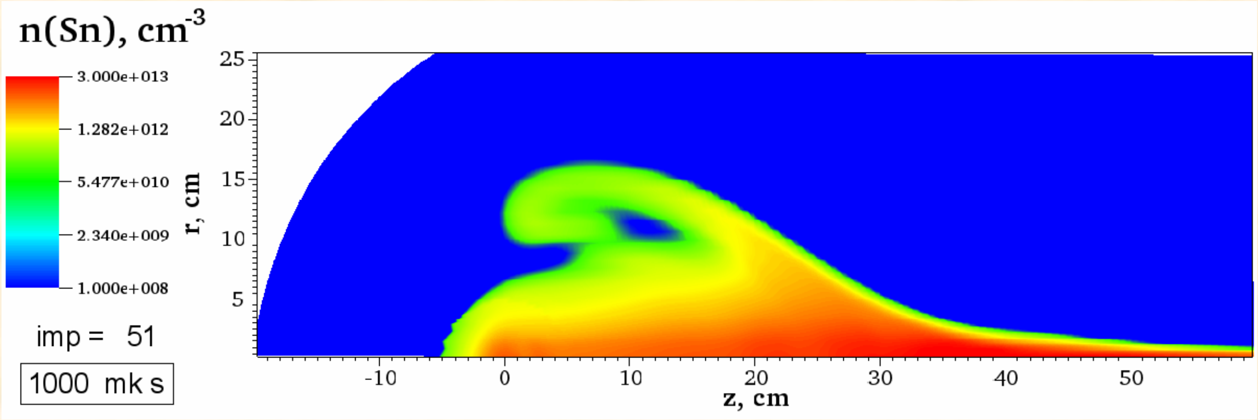
50
z, cm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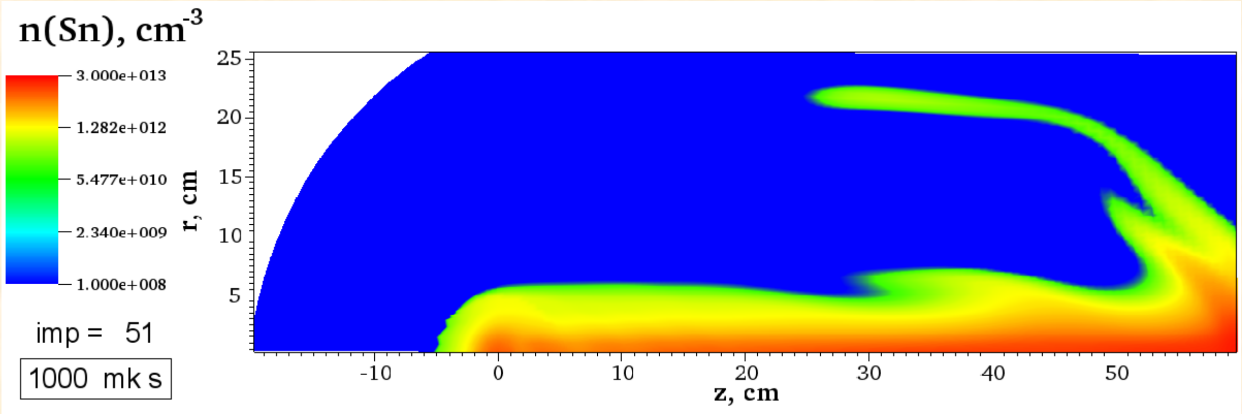
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r, cm
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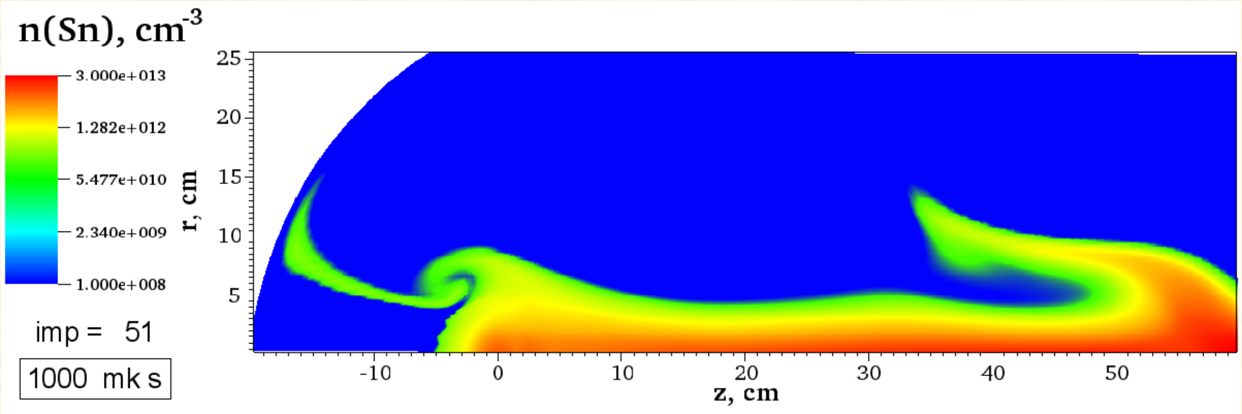
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imp = 51
1000 mk s
r, cm
z, cm

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